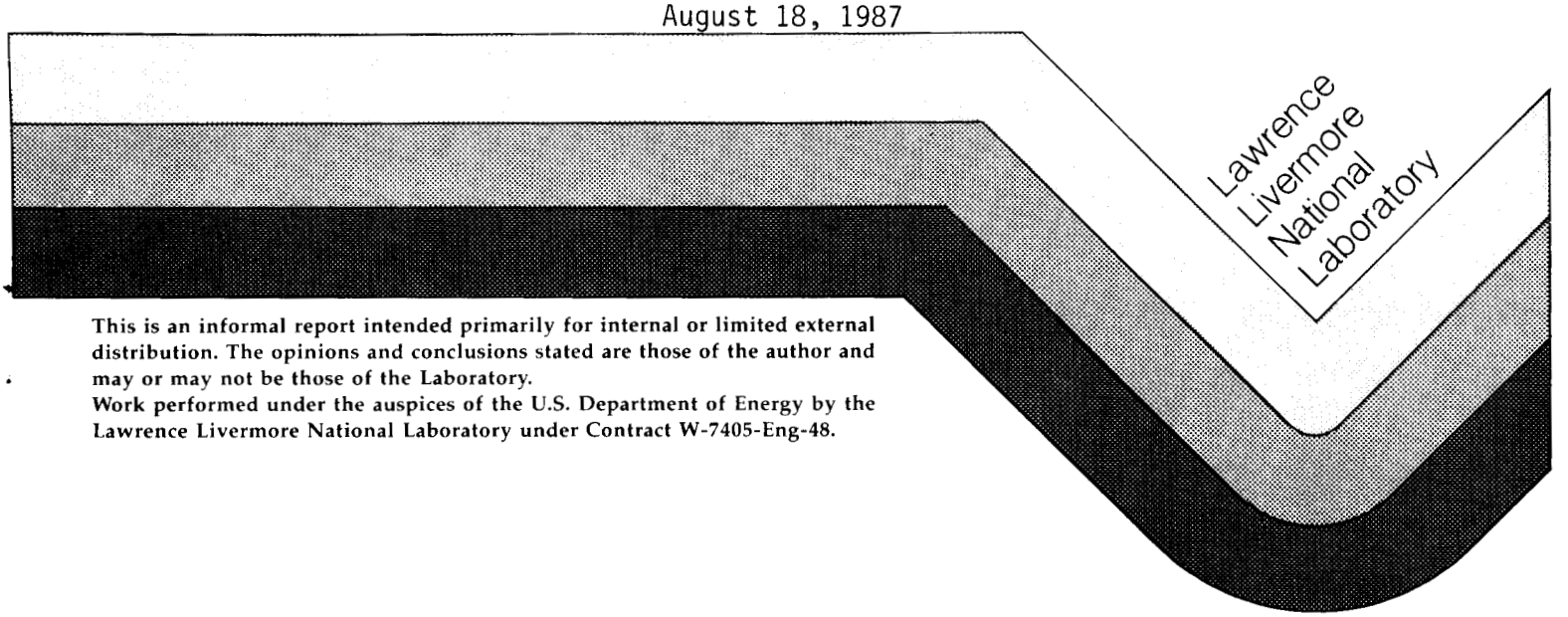
UCID-19227-86

U.S. ENERGY FLOW - 1986

I. Y. Borg
C. K. Briggs

August 18, 1987



Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

DISCLAIMER

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price Code	Page Range
A01	Microfiche
Papercopy Prices	
A02	001 - 050
A03	051 - 100
A04	101 - 200
A05	201 - 300
A06	301 - 400
A07	401 - 500
A08	501 - 600
A09	601

ABSTRACT

Although growth in the gross national product as well as total energy consumption in 1986 remained at 1985 levels, in detail there were notable changes in 1986. Industrial energy use fell to historical lows recorded in 1983 and all years prior to 1968. The drop is related to increases in end-use efficiencies and to changes in the make-up of the U.S. industrial sector. Imports of goods and services increased as well as crude oil.

The consumption of fuels for transportation increased for the third year by an amount approximately equal to the decline in industrial usage. Crude oil imports compensated for a slump in domestic oil production prompted by a downswing in worldwide oil prices. In contrast to the previous decade when the countries in the Middle East and Africa were the most important sources of imported oil and refinery products, in 1986 the three principal sources were Canada, Venezuela and Mexico. Petroleum products comprised a larger share of total oil imports from principal suppliers.

Transmitted electricity increased slightly in 1986 which was made possible by new nuclear capacity that came on line during the year. Cogeneration of electricity and process steam by industrial complexes continued to grow in part because of depressed domestic and Canadian natural gas prices and the favorable rates paid by the utilities for power that are assured by the Public Utilities Regulatory Act of 1978. Alternate sources of fuel for power production (geothermal, wind, solar, etc.) remained at 1985 levels and thus made only a small contribution to the total. The 1986 energy flow – supply and demand – is shown in graphical form using Department of Energy data.

INTRODUCTION

United States energy flow charts tracing primary resource supply and end-use have been prepared by members of the Energy Progam and Planning groups at the Lawrence Livermore National Laboratory since 1972[1,2]. They are convenient graphical devices to show relative size of energy sources and end-uses since all fuels are compared on a common btu basis. The amount of detail on a flow chart can vary substantially, and there is some point where complexity begins to interfere with the main objectives of the presentation. The charts shown here have been drawn so as to remain clear and be consistent with assumptions and style used previously.

U.S. Energy Flow – 1986
Net Primary Resource Consumption 74 Quads

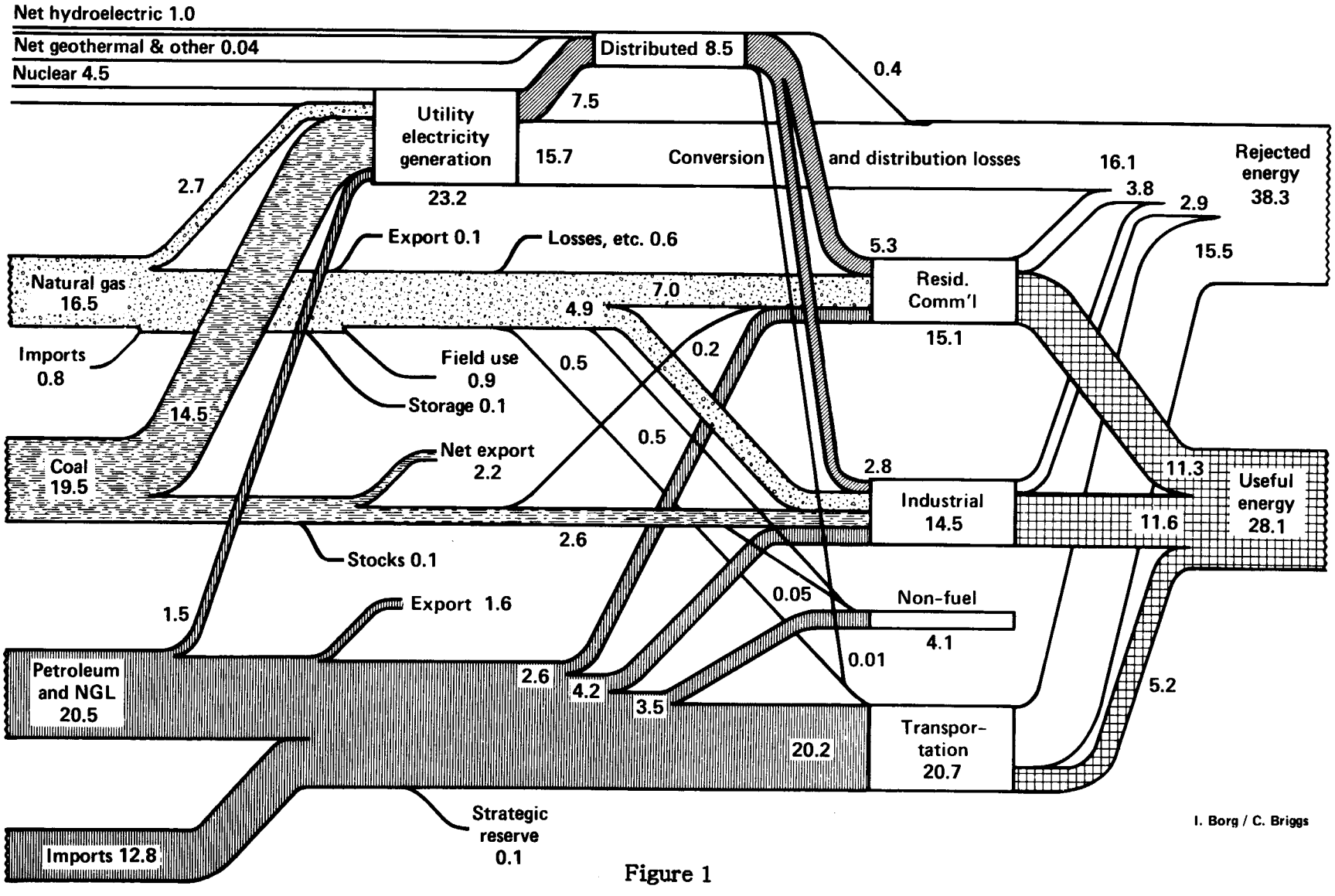


Figure 1

U.S. Energy Flow – 1985
Net Primary Resource Consumption 74 Quads

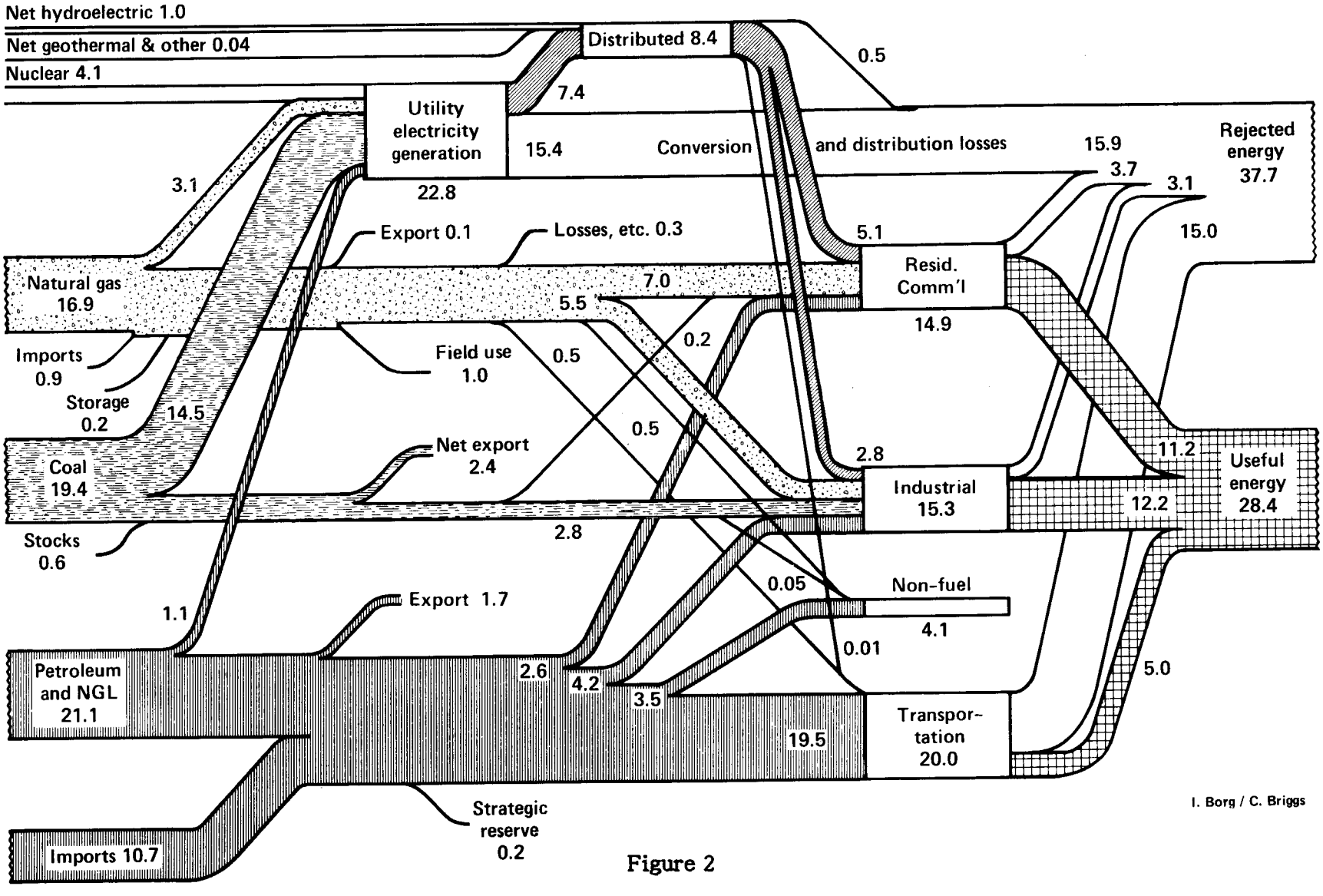


Figure 2

TABLE 1. COMPARISON OF ANNUAL ENERGY USE IN U. S.[4]

	Quads						
	1980	1981	1982	1983	1984	1985	1986
Natural gas	19.91	19.70	18.26	16.34	17.75	16.89	16.49
Imports	0.99	.90	0.93	0.94	0.86	0.93	0.75
Crude oil and NGL							
Domestic crude & NGL	20.50	20.45	20.50	20.53	20.96	21.14	20.53
Foreign imports (incl. products & SPR)	14.63	12.69	10.82	10.56	11.39	10.68	12.83
Exports	1.15	1.26	1.73	1.56	1.53	1.65	1.63
SPR storage reserve*	0.10	0.71	0.37	0.49	0.42	0.24	0.11
Net use (minus exports and SPR)	33.89	31.17	29.22	29.04	30.40	29.93	31.62
Coal (incl. exports)	18.54	18.33	18.60	17.29	19.70	19.39	19.48
Electricity							
Hydroelectric (utility) (net only)	0.94	0.89	1.06	1.13	1.10	0.96	0.99
Geothermal & other (net only)	0.02	0.02	0.02	0.02	0.03	0.04	0.04
Nuclear	2.74	3.01	3.12	3.22	3.55	4.14	4.48
Gas	3.81	3.76	3.34	3.01	3.21	3.14	2.70
Coal	12.12	12.58	12.58	13.23	14.09	14.54	14.46
Oil	2.63	2.20	1.57	1.54	1.29	1.09	1.45
Total fuel	22.26	22.46	21.69	22.15	23.27	23.91	24.12
Total transmitted energy	7.80	7.83	7.65	7.88	8.23	8.43	8.50
Residential and Commercial	15.09	14.55	14.64	14.29	14.48	14.88	15.03
Industrial	23.79	22.50	19.98	19.55	21.11	20.37+	19.54
Transportation	19.67	19.47	19.04	18.97	19.81	19.98	20.67
Total consumption** (DOE/EIA)	76	74	71	70	73	74	74

* Strategic petroleum reserve storage began in October, 1977.

+ Includes field use of natural gas and non-fuel category.

**Note that this total is not the sum of entries above.

ENERGY FLOW CHARTS

Figures 1 and 2 are energy flow charts for calendar years 1986 and 1985[3] respectively. Conventions and conversion factors used in their construction are given in the Appendix. For comparison with earlier years, consumption of energy resources is given in Table 1. These data represent substantial revisions of data initially published by the Department of Energy[5].

THE U.S. ECONOMY IN 1986

In most respects the economic growth in the U.S. in 1986 resembled that of 1985 (Table 2). However imported goods and services increased substantially during 1986. The decline in domestic oil production was compensated for by increased oil imports which accounts for a large part of the change (Figure 3). The amount of energy consumed per unit of GNP continued to decline from its 1970 peak reflecting increased energy efficiency in the industrial sector as well as changes in the mix of products comprising the gross national product.

Table 2. Economic indicators – percent change from preceding year[6] (based on 1982 $)

	Year	
	1985	1986
Gross national product	2.7	2.5
Personal consumption expenditures	3.5	4.1
Gross private domestic investment	-0.7	1.6
Export of goods and services	-2.0	2.3
Import of goods and services	3.8	10.4
Government purchases of goods and services	6.8	3.6

COMPARISON OF ENERGY USE WITH 1985 AND EARLIER YEARS

Total energy consumption in 1986 was close to that of 1985; however, there were substantial differences in consumption in major end-use sectors. Whereas industrial energy consumption fell by 4.0%, transportation use increased by almost the same amount (Table 1). The latter end use accounts for about 28% of all energy consumed in the U.S. and almost two thirds of all petroleum used.

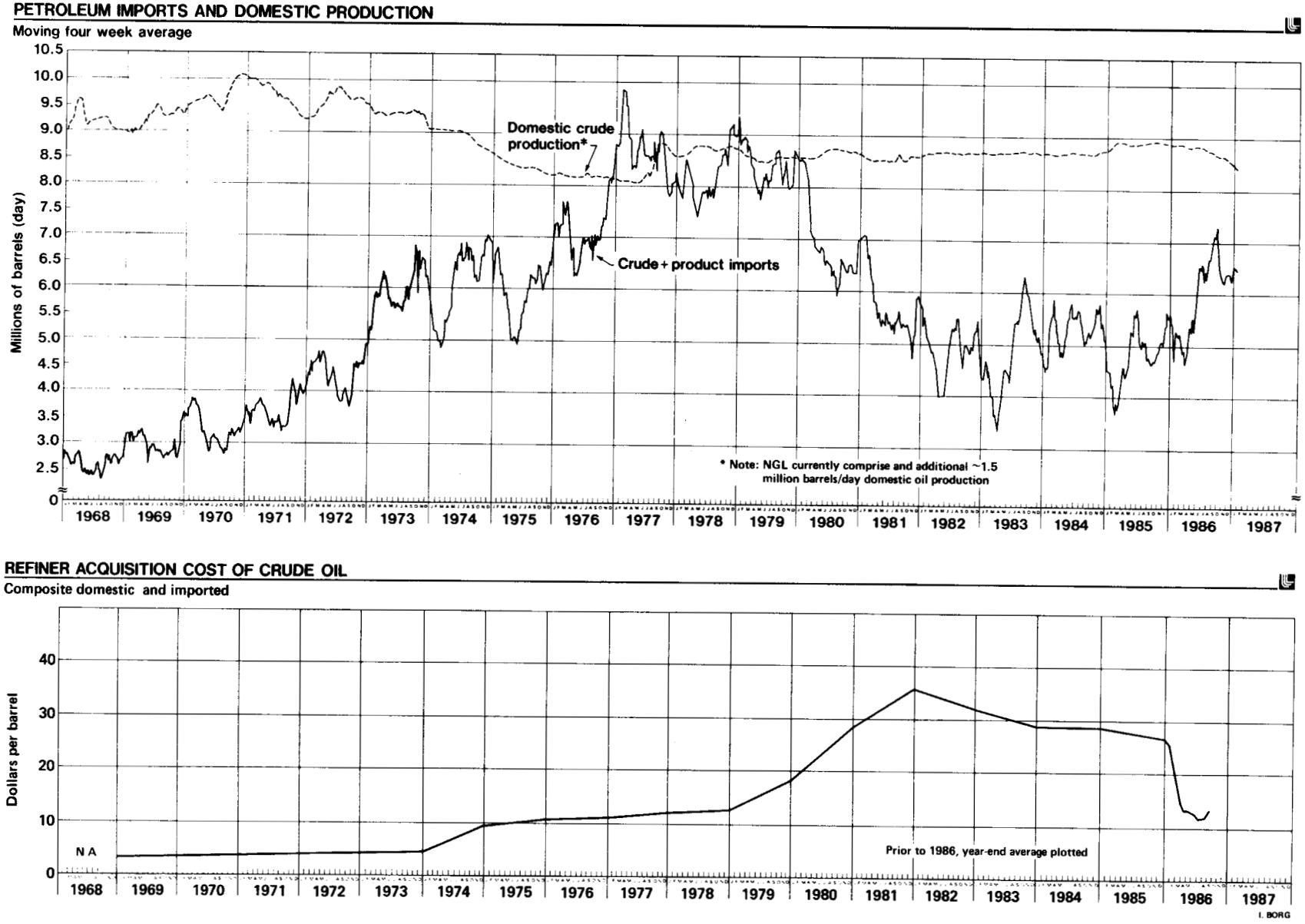

PETROLEUM IMPORTS AND DOMESTIC PRODUCTION
Moving four week average
Millions of barrels (day)
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
0
Domestic crude production*
Crude + product imports
* Note: NGL currently comprise and additional ~1.5 million barrels/day domestic oil production
1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987
REFINER ACQUISITION COST OF CRUDE OIL
Composite domestic and imported
Dollars per barrel
40
30
20
10
0
N A
Prior to 1986, year-end average plotted
1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987
I. BORG

Figure 3

In view of the mandated increase in vehicle fuel economy (26 mpg for the 1986 model year), the 1986 increase in the transportation end-use sector calls for comment. There has been an approximate 85% improvement in new car mileage in the last 15 years. However, because of the slow turnover in the fleet, it has resulted in a small improvement in the fleet average and has not been apparent in lower energy consumption (Table 3). The Department of Energy anticipates that the average efficiency of the fleet will rise from 15 to 23 mpg by the year 2010[8]. Historical trends and projections in the transportation sector are shown in Table 4 and Figure 4. The "reference case" projections over the 1985–2010 period equate to a 12.5% percent increase, which is quite a bit less than the population growth over the same period assuming population grows at 0.9% per year as it has in the 80's – crudely 22.5% over the same period. The fall in the price of crude oil and products (Figure 5) mitigated voluntary constraints on the use of motor fuels that have been in place for some years due to higher prices. The average U.S. price for unleaded regular gasoline fell from 120.2 cents per gallon (current dollars including taxes) in 1985 to 92.7 cents per gallon in 1986. Weakening of past price driven conservation together with the increase in the number of registered vehicles in the U.S. account for the increase in usage.

TABLE 3. PETROLEUM PRODUCTS*[4,7]

10^3 barrels/day (average)

	1978	1979	1980	1981	1982	1983	1984	1985	1986
Motor gasoline	7412	7034	6579	6588	6539	6622	6693	6831	7034
Jet fuel	1057	1076	1069	1011	1010	1050	1180	1220	1300
Distillate fuel oil	3432	3311	2866	2829	2671	2690	2845	2868	2914
Residual fuel oil	3023	2826	2508	2088	1716	1421	1369	1202	1418

*Refined petroleum product supplied: sum of production, imports, net withdrawals from primary stocks minus exports.

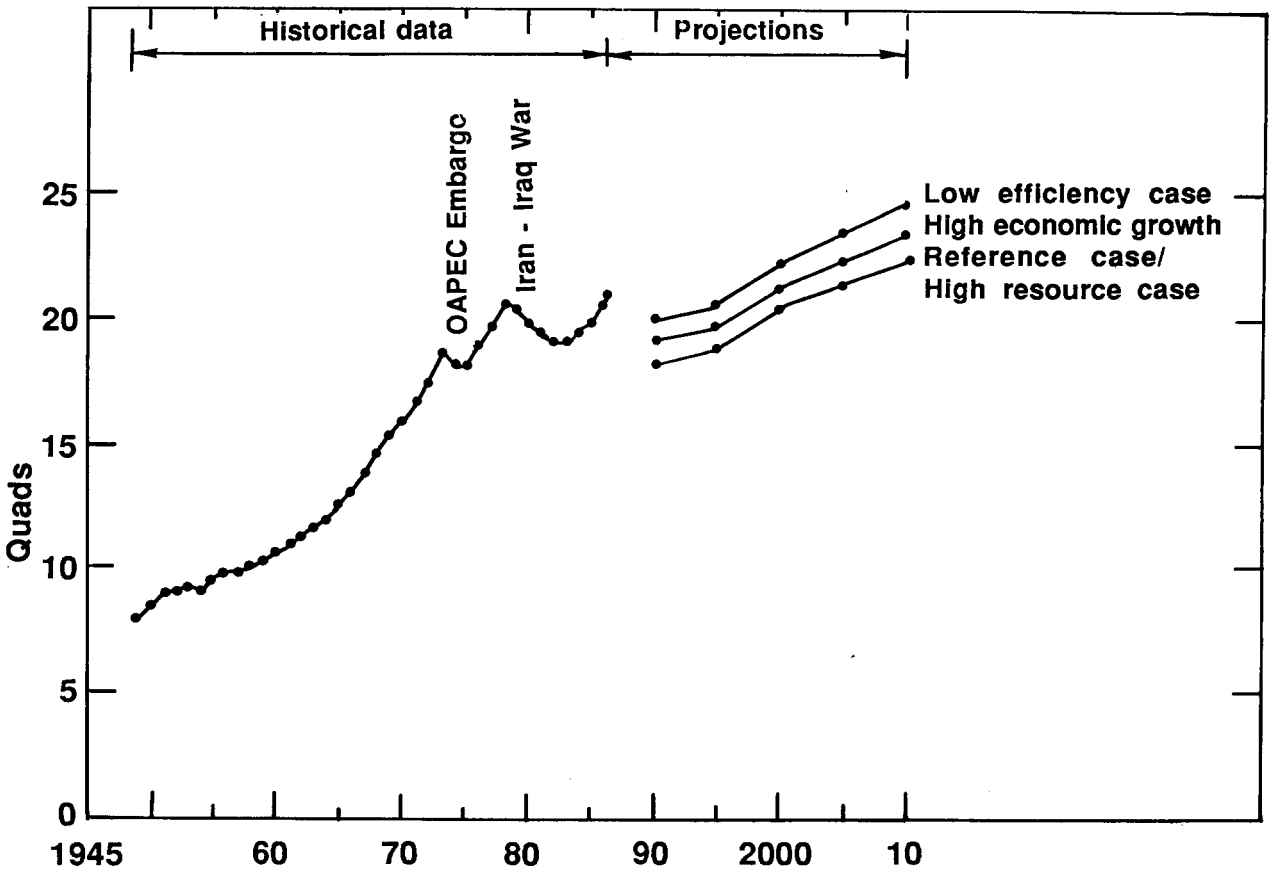


Figure 4. Energy used in U.S. transportation data from References 7 and 8

TABLE 4. ENERGY USED IN U.S. TRANSPORTATION[7,8]
(quads – 10^{15} btu)

		DOE Reference Case				
	1986	1990	1995	2000	2005	2010
Total U.S. energy use	74	87.3	93.1	98.5	104.2	110.8
Transportation	20	19.2	19.4	20.7	21.4	22.3

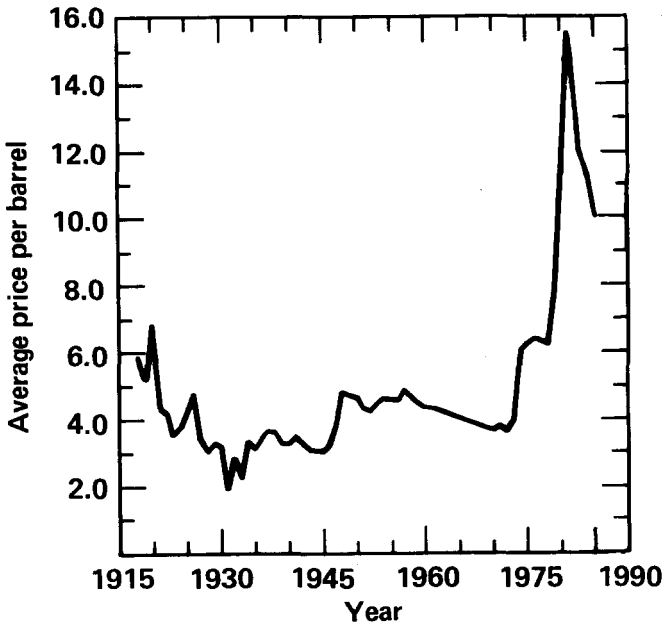


Figure 5. Price of U.S. crude oil (1973 dollars)

The approximate 4% decrease in energy use in the industrial and commercial sectors in 1986 brought the total below the previous lows recorded in 1983 and all years before 1968. The decline is attributed to increases in efficiency of industrial operations and expansion of the service trades at the expense of heavy industry[8]. The largest portion of the industrial decline was associated with decreased use of natural gas (Figure 1 and 2).

Lower crude oil prices depressed the U.S. domestic production and contributed to increased demand. Production declines were predominantly in the southwest and midwest but were partially offset by increases in Alaska. Production at Milne Point and Kuparak oil fields on the North Slope has augmented that at the supergiant Prudhoe Bay field. Conoco Inc., principal owner of the Milne Point field, at year-end was considering suspending production at the 10,000 barrel-a-day field because transportation costs to the West Coast - estimated to be $8 a barrel - have severely eroded profits in the depressed oil market[9]. The field was developed under the assumption when production started that world oil prices would be between $25-28 per barrel.

Well completions were 46% below 1985 levels, the consequences of which will be felt beyond 1986. Crude oil and product imports increased 20% during the year. In contrast to the 70's the three principal suppliers were Canada, Venezuela, and Mexico (Figure 6).

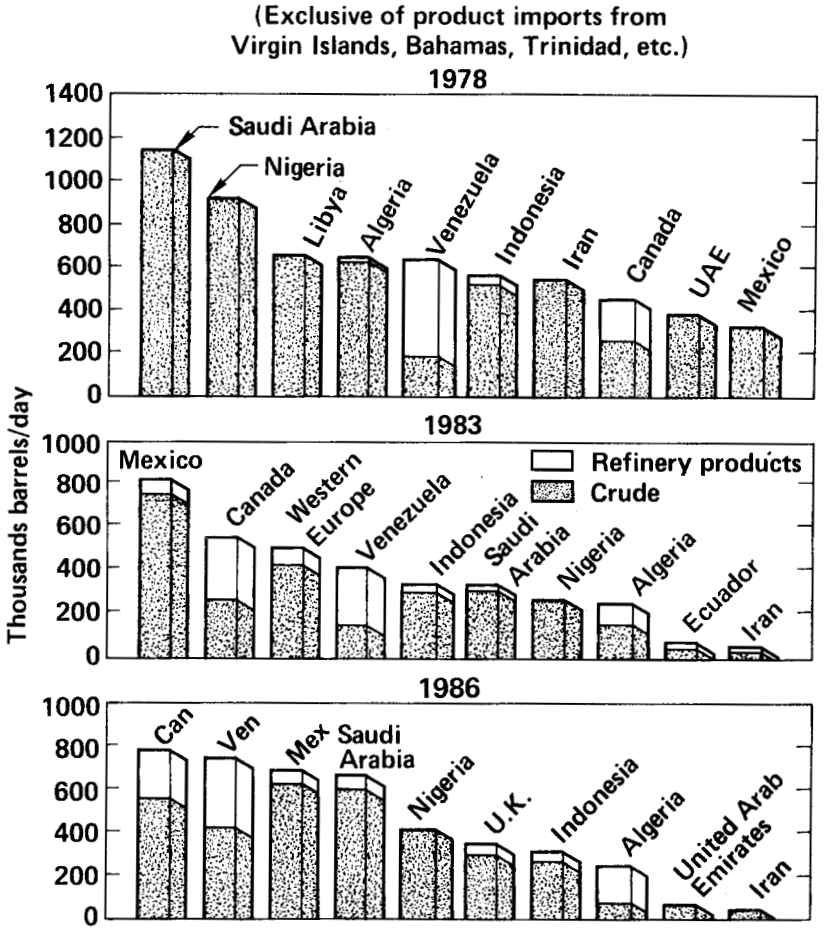


Figure 6. Source of U.S. oil imports

Despite partial price controls, the wellhead price of natural gas followed the decline in the price of oils. Prices were further lowered by gas transmission companies for large customers in order to forestall fuel-switching. Demand for natural gas did not increase in contrast to the effect of lower price on oil demand. Imports chiefly from Canada were sharply down as a consequence.

The production and use of coal virtually did not change in 1986. Eighty five percent of production goes into electrical power production. Although the worldwide demand for steam-coal increased, U.S. coal exports were stable and consisted primarily of metallurgical coking coals.

Electrical demand rose slightly in 1986. According to the National Coal Association the average capacity factor for steam generating coal plants was 51% implying a large under utilization of the 313 GWe of coal-fired capacity[10]. The contribution of nuclear power to the national grid increased; however, at 17% of electrical power generation it remained small relative to nuclear shares in France (70%), Belgium (68%), Sweden (51%), and eight other countries[11]. Power generated with natural gas declined by about the same amount as the increase in nuclear energy's contribution to the total generation. Use of oil for power generation increased somewhat; however, oil's contribution to power generation is still half of natural gas's and both are fuels for peaking and convenience rather than for base loads. Since the 1974 OAPEC embargo petroleum's use in power production has fallen and coal's use has steadily increased (Figure 7).

NUCLEAR REACTOR DEVELOPMENT

There were 126 reactors either operable or at some stage of construction at year end, and one cancellation (Seabrook 2) which was 22% complete. During 1986 five additional nuclear reactors were declared operable by the Nuclear Regulatory Agency (NRC), and seven were in a start-up stage, i. e. being loaded with fuel or undergoing low power testing (Table 5). Among the plants granted low power testing licenses were the Seabrook 1 reactor in New Hampshire and the Shoreham reactor on Long Island. Full power licenses for the two are far from guaranteed as controversy continued over plans for a ten mile evacuation zone surrounding both sites.

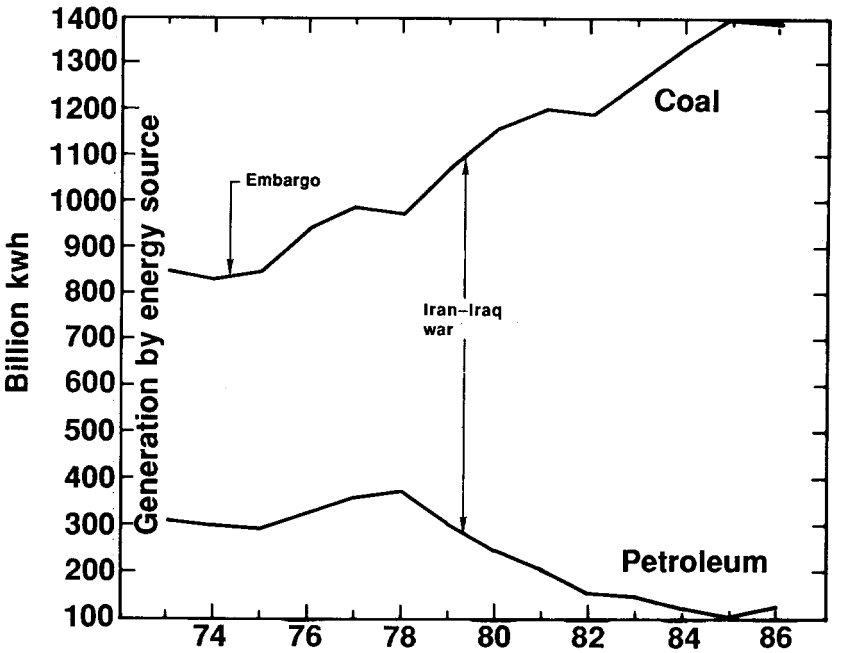


Figure 7. Use of petroleum and coal in U.S. electrical power production

TABLE 5. U.S. ELECTRICAL GENERATION[4]

	1984	1985	1986
Total electrical generation (bn kWh)	2416	2469	2489
Nuclear contribution (bn kWh)	328	384	414
Percent nuclear	13.6	15.5	16.6
Installed nuclear capacity (GWe)**	69.5	79.4	85.2
Number of operable reactors	86	95	100*
Annual capacity factor (%)	56.5	58.5	56.9

* An additional 7 reactors are in start–up status

** Net summer capability of operable reactors

The Chernobyl accident in the USSR in April of 1986 focused government and public attention on all potential and actual reactor failures. In July the NRC released a list of the 16 most problem plagued plants in the U.S. They included three Browns Ferry reactors and two Sequoyah reactors operated by the Tennessee Valley Authority in Alabama and Tennessee, respectively; Davis-Besse near Toledo, Ohio; Turkey Point 3 and 4 in Turkey Point, Florida; Fermi 2 at Lagoona Beach, Michigan; two LaSalle reactors at Seneca, Illinois; Fort St. Vrain in Platteville, Colorado; Rancho Seco at Clay Station, California; two reactors at Peach Bottom in Pennsylvania; and the Pilgram plant at Plymouth, Massachusetts[12]. At the time of the report only the Peach Bottom reactors were operating. Upgrading has been going on at many of the sixteen reactors for several years, and at year end repairs and modifications at Fort St. Vrain, Rancho Seco, Fermi 2 and three of the TVA reactors were completed or nearing completion. The problem plants tend to be either Babcock and Wilcox PWR's or General Electric BWR's, but every major reactor manufacturer except Combustion Engineering is on the list. The NRC identified management difficulties going back many years as a common denominator at many of the ten reactor sites containing the sixteen reactors.

In the course of 1986 other nuclear plants sustained failures. Four workers at the

accidents had been reconsidering the nuclear option as evidenced by the lack of reactor orders and cancellations during the last decade. In the case of the utilities, the factors influencing their decisions have been reconsideration of the need for additional power, rapidly escalating costs associated with construction of nuclear power plants and financial risks posed by unforeseen delays, sometimes measured in years, in reaching commercial production. Nuclear plants nearing completion in 1986 have cost $5 to $6 billion, e.g. Nine Mile Point 2, New York and Seabrook in New Hampshire. Many plants operating for the first time in 1986 such as Clinton, Hope Creek, Shoreham, and Millstone 3 cost between $2700 and $4020 (1984 $) per installed kW[13]. Compare that to $700 per kW (1982 $) for plants started in 1966–67 according to EIA estimates given at the Atomic Industrial Forum[14]. Because longer construction times are associated with large plants, the usual economies of scale have not been realized; hence, for financial reasons it seems likely that any future nuclear plant orders in the U.S. will be for smaller units. For safety reasons the Reagan administration is proposing standardization of plant design as well as reform of the licensing process. Bills covering these issues were in committees of both houses of Congress by year–end[15].

COGENERATION

The move to cogeneration of process steam and electricity on the part of U.S. industrial firms continued to grow in 1986. Industries that have used cogeneration in their operations include the refineries, oil companies with enhanced oil recovery operations, such as in the heavy oil fields in California and Texas, petrochemicals and paper products. Exact tallies of the amount of electrical capacity associated with cogeneration plants are not available for the year; however, the amount is believed to be in excess of 26 GWe[16] out of the total 666 GWe in the country. Applied Energy Services predicts that it could reach 150 GWe by 2000[16].

Impetus behind the growth of cogeneration has been the Public Utilities Regulatory Act of 1978 that requires utilities to buy the power produced by the cogenerators at "avoided costs", i.e. at prices commensurate with those associated with construction of new, conventional power plants by the utility. There is considerable leeway in interpretation of what "avoided costs" are from state to state depending on the state and local utilities available fuels. Natural gas has proven to be the most common fuel used in large cogenerating facilities primarily because of its availability and depressed prices.

Wood waste and refuse are also common cogeneration fuels; but the individual facilities are small. Whether natural gas's popularity will persist into the next decade is uncertain as by all predictions the "gas bubble" of 1985–6 ultimately will disappear.

The largest cogeneration plant conceived to date is the conversion of the mothballed Midlands nuclear power plant in Michigan (1300 MWe) to a gas–fired combined cycle cogeneration plant. Dow Chemical Company will use the process steam in its Michigan plant. The plan passed a major regulatory hurdle with the Federal Energy Regulatory Agency in Spring of 1987.

While utilities initially viewed cogeneration as competition and a loss of industrial markets for electricity sales, some have come to view the plants as delaying the day when they will have to build and finance large baseload plants. In recent years construction of such plants has been attended with uncertainties concerning the decisions of regulatory bodies as to whether the full cost can be passed onto the ratepayers. Since recent regulatory and court rulings require the utilities to provide back–up electrical service to cogenerators, the utilities are hoping to charge a premium for such service.

From the cogenerator's standpoint the plants represent a cost–cutting move since the cost of electricity generated with natural gas can be as low as 4 cents per kWh, compared to as much as 12 cents per kWh for some recently completed nuclear plants. The future of cogeneration is essentially in the hands of the regulators since they determine the prices received for the electricity sold to the utilities. If "avoided costs" are based on coal–fired electrical generation costs, and if as expected the price of natural gas increases appreciably in the future, cogenerators may see their profit margins materially eroded.

APPENDIX

Data and Conventions Used in Construction of Energy Flow Charts

Data for the flow chart were provided by tables in the Department of Energy Monthly Energy Review, DOE/EIA-0035[4], the 1986 Annual Energy Review[7] and the Quarterly Coal Report[17].

The residential and commercial sector consists of housing units, non-manufacturing business establishments, health and education institutions, and government office buildings. The industrial sector is made up of construction, manufacturing, agriculture, and mining establishments. The transportation sector combines private and public passenger and freight transportation and government transportation including military operations.

Utility electricity generation includes power sold by both privately and publicly owned companies. The non-fuel category of end-use consists of fuels that are not burned to produce heat, e.g., asphalt, road oil, petrochemical feedstocks such as ethane, liquid petroleum gases, lubricants, petroleum coke, waxes, carbon black and crude tar. Coking coal traditionally is not included.

The division between "useful" and "rejected" energy is arbitrary and depends on assumed efficiencies of conversion processes. In the residential and commercial end-use sectors, a 75 percent efficiency was assumed which is a weighted average between space heating at approximately 60 percent and electrical lighting and other electrical uses at about 90 percent. Eighty percent efficiency was assumed in the industrial end-use sector and 25 percent in transportation. The latter percent corresponds to the approximate efficiency of the internal combustion engine.

There are some minor differences between total energy consumption shown here in the energy flow charts and the DOE/EIA totals given in Table 1. We use net hydroelectric power in flow charts rather than the gross amount, which is customarily included in DOE/EIA totals. The net figure is calculated from the total number of kilowatt hours produced by hydroelectric sources. Thus the sum of individual contributions to annual energy consumption shown in the energy flow charts will be smaller by several quads (10^{15}btu) than total published by DOE/EIA and given at the top of the chart and in Table 1.

Conversion Factors

The energy content of fuels varies. Some approximate, rounded conversion factors, useful for estimation, are given below.

Fuel	Energy Content (Btu)
Short ton of coal	22,400,000
Barrel (42 gallons) of crude oil	5,800,000
Cubic foot of natural gas	1,000
Kilowatt hour of electricity	3,400

More detailed conversion factors are given in the Department of Energy's Monthly Energy Review.

REFERENCES

1. A. L. Austin, Energy Distribution Patterns in the U.S.A. for 1970 and 1985, Lawrence Livermore National Laboratory Report UCID-16022, 1972.
2. I. Y. Borg, Energy-Flow Diagrams: An LLNL Contribution to Energy Analysis, Energy and Technology Review, p. 15, May 1984.
3. C. K. Briggs and I. Y. Borg, U.S. Energy Flow - 1985, Lawrence Livermore National Laboratory Report UCID-19227-85, July 1, 1986.
4. Monthly Energy Review, DOE/EIA-0035 (86/12), March 1987.
5. Monthly Energy Review, DOE/EIA-0035, (83/03), June 1983, p. 36.
6. Survey of Current Business, U.S. Department of Commerce/Bureau of Economic Analysis, Table 8.1, February 1987.
7. Annual Energy Review, 1986 DOE/EIA-0384(86), May 1987.
8. National Energy Policy Plan Projections to 2010, DOE/PE-0029/3, December, 1985.
9. The Energy Daily 14, December 8, 1986, p. 1.
10. The Energy Daily 15, April 21, 1987, p. 2.
11. I. Y. Borg, Present and Foreseeable Nuclear Power Generation as a Reflection of Individual Countries Resources and Objectives, Lawrence Livermore National Laboratory Report UCRL-53804, June 26, 1987.
12. K. Maize, "Nuclear regulators unveil rogues' gallery", The Energy Daily 14, July 16, 1986, p. 1.
13. C. Stein, "The Stone and Webster effect", Boston Globe, July 8, 1986.
14. The Energy Daily 14, April 4, 1986, p. 3.
15. "Build nuclear plants with standard designs", The State, July 13, 1986, p. 2-B.
16. The Energy Daily 15, June 17, 1987, p. 3.
17. Quarterly Coal Report, DOE/EIA-0121(86/4Q) Table 31, April 1987.

Technical Information Department · Lawrence Livermore National Laboratory
University of California · Livermore, California 94550